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"Injection Molding by Injection Molders"

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JANUARY 20, 1966

Sheraton-Cleveland Hotel
Cleveland, Ohio

SOCIETY OF PLASTICS ENGINEERS, INC. • CLEVELA

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"INJECTION MOLDING BY INJECTION MOLDERS"

Regional Technical Conference

Sponsored by

Cleveland Section

Society of Plastics Engineers, Inc.

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8442-1

A RE-EVALUATION OF SCREW INJECTION MOLDING

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THE EARLY DAYS OF SCREW INJECTION MOLDING

As we look back several years into the first days of screw injection molding, we find that, as in any new venture, the first steps were rather slow and unsteady. Resistance to change is always present and there were many who just couldn't see the possible benefits of this new concept of injection molding. A number of us met here to learn more about this new method of molding and, as I recall, many lively discussion groups argued the pros and cons of screw molding, but many of us left not fully convinced of the alleged benefits of the system. Those who did not believe that an extruder screw could do as efficient a job as an injection were not convinced while some custom molders who were operating screw machines were very enthusiastic.

The new screw machines were able to overcome some of the problems that had plagued the industry for years, such as poor color dispersion and erratic operation of the plasticizing systems, but new problems were created. Screws bent and scored, extruder barrels split and drive units failed. This was an entirely different concept of injection molding after many years of straight plunger molding.

The first changes in the system were the two stage plunger preplasticizer pioneered by Crown Machine during the late 1940s and followed by the first "piggy back" units that utilized a conventional plunger cylinder mounted above a secondary shooting cylinder.

The first reciprocating screw machines originated in Europe and were much too slow for our high speed molding requirements; however, the machines had some obvious advantages in certain types of molding.

RESISTANCE TO CHANGE

In an industry such as injection molding where there has been little written information to guide the processor and where most molders had fought for years to develop the methods that allowed them to remain competitive, it is often difficult to present a new concept and gain immediate acceptance. This was true of the reciprocating screw machine. Some molders tried them and had excellent results while others ran into all kinds of trouble. In general, we found that custom molders who were running many different materials on the same machines were quick to see the advantage of the screw machines while those molding proprietary items or appliances or houseware parts that were large found less use for the equipment.

Machinery manufacturers offered both types of equipment and the choice was left up to the molder. It was an uncertain period in the manufacture of molding machines.

A COMPARISON OF PREPLASTICIZER AND RAM TYPE MACHINES

Actually, the controversy of several years ago was between the preplasticizing molding machine and the older plunger method. The reciprocating screw is actually a preplasticizer of a simple type, using the very efficient extruder screw as a means of plasticizing the material and, also, functioning as the plunger to inject the material into the mold. The preplasticizer had many advantages over the straight plunger machine, such as:

1. Shorter cycles due to faster injection speeds and lower material temperatures.

2. Larger shot sizes due to the preplasticizer principle which allowed us to store melted material prior to injection.

3. Better color dispersion due to the more efficient mixing action of the extruder screw compared to the in-line action of plunger machines.

4. Strain-free molding resulting from better plasticization of material and lower injection pressures and heats.

5. Better utilization of equipment because the preplasticizer could mold a larger shot and often required less clamping tonnage.

It has been generally accepted that the preplasticizer is a much more versatile machine than the plunger type and allows the molder to operate with fewer uncontrolled variables. This indicates that the preplasticizer principle, whether it be two stage plunger, two stage screw or reciprocating screw, is superior to the plunger type principle. There are, however, drawbacks in that the machines have become much more complicated and require more maintenance. This is especially true of the two stage units.

The big question confronting molders several years ago was, "Should they invest in the new untried machines and possibly gain important competitive advantages or stick with the proven plunger machines and possibly face obsolescence and the possibility of not being competitive?" The general trend was for custom molders to go along with the screw machines and for many of the proprietary molders to develop a "wait and see" attitude.

A number of years ago the housewares molders and appliance molders realized that the preplasticizer machine would do a better job than plunger machines and, actually, many large parts such as refrigerator door panels and garbage cans could not have been molded on plunger machines. It was a natural transition for these molders to change to the two stage screw machines, and it was found that the extruder, if of the proper size and type, could do a better job of preplasticizing material than the two stage plunger. The early reciprocating screw machines lacked adequate shot size, injection pressure, and shot control.

One distinct disadvantage of the extruder preplasticizer was discovered and is still a problem. When called on to produce the high temperature melt required for today's large, thin-walled moldings, especially in the polyolefins, the output of the extruder falls off rapidly. For example, a 4-1/2" extruder rated at 750

pounds per hour at a stock temperature of 400°F. will drop to an alarming 300 pounds per hour when producing the 550°F. melt necessary to fill thin wall garbage can molds. The same problem occurs when back pressure on the screw must be raised to allow the screw to do an efficient job of color dispersion on dry blends or color concentrate blends. This same problem is true of plunger preplasticizers but to a much lesser degree as the plunger acts as a more efficient positive displacement unit.

There was little improvement in color changing between the extruder and plunger type preplasticizer machines.

A GRADUAL CHANGE TO SCREW TYPE TWO STAGE MACHINES

In recent years the two stage plunger machine has decreased in popularity and has been largely replaced by the two stage extruder machines.

There have been a large number of plunger and two stage plunger machines converted to two stage screw machines and to reciprocating screw machines. The two stage screw conversion could often be made at a lesser cost than a reciprocating screw as some of the original injection components could be used. These conversions have seen varying degrees of success. The units designed by machine manufacturers to fit a particular machine have been fairly successful and many of the "shop made" units have been well worthwhile.

My experience in the conversion of machines from 400 to 1000 ton capacities has indicated that both factory and "shop made" units have been hard to maintain, due to the overloading of hydraulic circuits and clamping capacity. Most of these machines were ten to fifteen years old and were not designed for the high speed operation offered on today's machines, nor were they designed to mold shots two or three times the size of the original rating. When additional pumps were added to correct the speed, serious problems occurred with circuit overloading, overheating of oil and mechanical failures.

Many converted machines utilized used extruders of various pedigrees that were largely inadequate and were difficult to maintain. We must remember that most extruders were not designed for stop and start operations on a fast cycle. The amount of down time was often enough to erase any gain in cycle due to the conversion. There have been instances where machines were connected back to plunger operation to avoid the excessive down time. In some cases, serious trouble developed with drive units, thrust bearings, barrels and screws.

A GRADUAL UPGRADING OF RECIPROCATING SCREW UNITS

The first reciprocating screw machines were relatively small in size and shot capacity, but the past few years have brought a gradual improvement in the units until now machines of 1500 ton and 250 ounce shot size are available. Screw machines range from small units using a 1-1/2" diameter screw to 6" extruders. The entire range of machine sizes is available. Drive sections have been greatly improved and adequate units are available in both electric and hydraulic types leaving the molder a choice in this area.

Screws have been greatly improved to help eliminate the earlier tendencies toward bending and galling. Screws are available in general purpose types that will handle most materials, and specials are available for troublesome materials or higher output rates, if necessary.

Non-return check valves have been improved greatly over the earlier models and this critical problem of the first reciprocating screw machines is much less critical, although it is still one of the most troublesome areas. Close tolerance work demands a positive seal at the end of the screw to enable the molder to maintain pressure in the mold. More work is necessary in this area.

A COMPARISON OF RECIPROCATING SCREW AND PLUNGER MOLDING

When we directly compare the reciprocating screw with the plunger type machine, we find the same advantages offered by the two stage preplasticizer plus several advantages common to the reciprocating screw:

1. Better plasticizing of material
2. Lower heat
3. More pressure on material
4. Positive metering of shots
5. Less heat variation on material
6. Faster cycles
7. Better parts
8. Smaller machines for larger parts

Advantages of the reciprocating screw are:

1. Easier color changes
2. Less chance of material "hang up" allowing molding of "heat sensitive" materials
3. Simpler construction
4. Freedom from plunger leakage
5. Elimination of directional material cut off valves

These additional advantages of the reciprocating screw machine, coupled with the fact that many of the earlier faults have been eliminated, indicate that these machines definitely are more versatile.

SUMMARY

It cannot be said

We can by no means say that the reciprocating screw machine has completely obsoleted the plunger machine for there are far too many of these machines producing good quality, competitive moldings today; however, it is evident that there are fewer plunger machines offered for sale today and they're only in the smaller sizes.

The price differential that was apparent at first appears to be slowly adjusting itself.

The early complaints of excessive maintenance on screw machines have been generally solved. It is usually no more difficult to maintain a screw machine than a plunger machine. A damaged screw is no more serious than a scored plunger, and drive units are fairly trouble free.

The next few years will be extremely interesting for, as the screw machine becomes the standard of the industry, we will be anxiously awaiting the next developments in the injection molding industry.

8442-2

WHY SCREW MACHINES OVER PLUNGER MACHINES?

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To clarify the reference, a molder shall be identified as that group of people which has been assembled together to perform the task of converting thermal plastics materials to a molded form by the use of injection molding machines.

A molder must possess many talents; they must have a favorable knowhow of mechanical engineering, metalurgy, thermal physics and moldability of various molding materials to properly design, build and utilize molds suitable for their requirements. They must have knowhow to select proper molding materials to suit their requirements, and also the ability to maintain their operation to provide the molded product with all the favorable characteristics of the selected material. They must also fully understand their molding machines in every respect to tie these first two factors together cycle after cycle, day after day, to produce satisfactory products.

The machine is a complex device which serves three prime functions:

1. To open and close the mold, holding pressure on the mold while closed to permit filling of the cavities.

2. To plasticize the material.

3. To inject the material into the mold.

Many machines have been selected in the past on their ability to perform one or two of the three functions with the molder enduring many problems with the other function. The most neglected factor without question was the ability to plasticize material.

Common practice has been to combine the plasticizing function and the injecting function in most machines and this has been described as a plunger machine. Only in two stage plunger machines have we separated these two functions.

Let us look at the problems we have encountered with the plunger machine. Let us assume the molder has mastered all the many talents required over molds, material selection, clamp operation of the molding machine, finishing operations, water supply, manpower, and scheduling. Now we concentrate our attention on the device that will come in direct contact with $350,000 to $1,500,000 worth of material in its lifetime. This device also has the distinction of contacting with contamination this vast amount of valuable material at its most vulnerable state, in its unplasticized state. If for no other reason than to keep the material free of

danger from loss, here it would deserve our prime attention. But in addition to its exposure to our prime product, it must also induce heat into the very core of each granule which, in its defense to our purpose, has the inherent quality of refusing to accept this heat by its insulating qualities and attempts to remain a solid at room temperature as it was when it entered the hopper of the molding machine.

The molder was faced with a device that would force from its nozzle a shot of material that had a variance of 50 F. within its content. We were forever attempting to lessen this variable by means of preheating the granules in the hopper, decreasing the cross section of plastics area in the heating chamber, driving the material through small origices to generate frictional heat, putting internal heaters in the torpedo, using higher wattage heaters on the heating chamber, and even placing strainers in the flow of material such as the polyliner. How badly we mutilated the material with these improvements was very obvious, reds turned orange, whites had yellow streaks, and physical properties of the material which resulted were a disgrace to our industry. At the best, the heating cylinder straining to maintain plasticizing capacity for a fast cycling clamp was a calamity if the cycle were momentarily interrupted and interruptions were common, due to the irregular melt causing parts to stick in the mold or the nozzle to drool.

The effective molding pressure on the material at its point of entrance into the mold on a plunger machine was and remains to be a well guarded secret. Perhaps it is not important that we know what it is, but it is most important that once we fill the mold properly we can continue to achieve like pressure. On a plunger machine if we change the melt temperature either by a runaway heat control or a cycle interruption, melt temperatures change, then the pressure. Most of us have cleaned flashed molds to the extent we will never forget this ever present characteristic. This performance of the plunger machine has caused two words to become the most universal words used by the operating personnel of injection molding plants; they are "shorts and flash". The immediate reply of any operator when questioned on the cause of poor production performance has been for twenty-five years the usage of these two words, until most all management in our industry cringe at the very mention of them. Strangely enough, the plunger machine with its ability to have ever varied effective pressures has made these two words link together like twins.

The more improvements we devised to help the plunger plasticize, the more complex the unit became and the more ever present were leaking joints, material hangup causing overheating of portions of the shot, and areas which defied us to change colors or materials. Many times the molder was faced with a most difficult decision - shall we run dirty contaminated parts for several hours or shall we shut down and work several hours dismantling the device to clean it? We also found many opportunities to decide whether to run the device with its leakage of valuable material or stop and reseat the joints. This last alternative has many degrees of possibilities also.

One of the most imposing decisions a molder faced was a cracked torpedo or heating cylinder seat. This fault could dirty hundreds of dollars worth of material or if replaced could cost more than the profit of his entire production run. We are all aware of the decisions that were made that really hurt our industry.

The two stage plunger machine had the impressive advantage of giving the molder shot control providing he had large and efficient maintenance crews. We could spend much time on the problems - shooting rams, leaking, gaulding, grinding dirt into the plasticized material, and forever leaking joints. Let us say many overtime hours were spent and much material joined the scrap pile in this endeavor.

A short time ago, the industry viewed a sudden change taking place in Europe and we reluctantly faced the fact that we could be wrong in our common acceptance of the plunger principle being the best means of converting material to a plasticized state.

We stopped to realize that we had ignored the device that we would use if our only objective was to plasticize material. The extrusion industry used the screw for the ultimate control of plastification, and material processers used it, and even the injection molder used it, if he wished to precolor and pelletize material. Why not use it on the section of the injection molding machine between the hopper and mold?

Let us look at the reasons we should try this device. We know that the screw with proper compression ratio and L to D ratio will produce the ultimate in melt uniformity when run continually. We know it is self cleaning and has a minimum of areas for material hangup. We know it generates heat frictionally and may even run without outside heat being induced and will produce even temperature melt shot after shot. We know it can be interrupted without overheating to certain limitations. We know to completely replace the screw and barrel is cheaper than replacing heating cylinder assemblies. It can be quickly cleaned. It will change materials or colors unbelievably quick. It does not require ultra-positive feed control of raw material. It will measure shot size accurately and consistently. It never need be purged. Its original cost is comparative to a plunger type heating cylinder. It possesses less joints to leak. It gives us material in shot size at the easiest possible place to direct positive known pressure on it to inject into the mold, so we will know pressure available and control it. Its simplicity endears it to all molders very quickly from a maintenance standpoint.

After such an impressive group of factors in its favor, we tried this device with very reluctant minds. After all our plants were full of plunger machines, our factories were engineered and tooled to build plunger machines, and our salesmen were reluctant to learn a new line. We must pay a tribute to a superior device with means of converting material more satisfactorily when we observe the acceptance of the reciprocating screw machine. This is not a fad; it has proven itself. Let us review some of its remarkable performance.

WHAT THE SCREW MACHINE CAN DO

1. 30% to 50% more production with other factors being equal.
2. Quick material changes with minimum loss of materials.
3. Better quality of molded parts.
4. Color changes greatly improved.
5. Run materials that the plunger machine could not properly plasticize.
6. Produce shots with uniform melt temperatures.
7. Minimum contamination of materials.
8. Better color distribution when dry coloring.
9. Minimum leakage of plasticized material.

10. Accept interruptions without purging.

11. Win friends within the operating personnel because of ease of operation and maintenance.

WHAT THE SCREW MACHINE CANNOT DO

1. Correct for improper molds.

2. Upgrade material.

3. Increase production if other factors are at fault.

4. Run properly without being understood and being properly adjusted.

Now we are integrated with this device to the point we are sure it has a large part to play in our future. We accept it as a means of playing an important part in our molding operations. It cannot cure all our problems but it has proven to be the best means of plastification and simplifies our molding task by relieving us of many limitations the plunger machine saddled on us. Let us take it for its benefits and use it as the answer to our plasticizing problems and not judge it by any other measure. If it is to be criticized, it must be reasoned its failure was due to a factor we can correct.

We must use great care in selecting the size of unit to match a machine as we desire a unit large enough to "recover" within desired cycle limitation, and yet not be too large so that it is idle a high percentage of the time given it for recovery. This size consideration, like many other factors to study in selecting a molding machine, convinces us that machine sizes become ever more critical and one standard machine cannot accept a large group of greatly varied molding jobs. We must develop more specialized machines for specific jobs and not try to have one machine do everything.

We cannot judge the principle of a machine if it is improperly sized. We feel that each of us benefits when our industry makes an important advancement. Surely the screw machine principle is such an advancement and we all may take pride in the improved product which is a direct result of its usage.

Never should we as molders feel we have achieved the ultimate. In mold design a challenge remains: in material selection, better qualities are constantly offered; in molding machines better techniques are to be sought. I am firmly convinced the screw principle is our best means of future advancement and that we should direct our ingenuity to its betterment in supplementing our success.

8442-3

QUALITY PRODUCED BY RECIPROCATING SCREWS

Frank E. Schneider

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The topic of this discussion is quality as produced by reciprocating screws.

The introduction of reciprocating screws in this country a few years ago was surrounded by an aura of high anticipation and a panacea expectation - at last the answer to the maiden's prayer had been found - so to speak.

There was much "ballyhoo" associated with the screw which was fostered and enhanced by certain machinery manufacturers. An example of this attitude was expressed to me by an engineer working for a major appliance producer who indicated he wanted no parts for his company unless the parts were produced by a screw. When quizzed as to the reason for this statement, the reply was based on the theoretical assumption that better plasticizing meant better parts.

Quality parts do not automatically come from reciprocating screw machines. Quality molders probably are producing quality parts more consistently, but I doubt if the quality of parts produced as an average is much better than was produced by the so-called conventional machines.

When I speak of quality, I'm thinking of dimensional control, appearance, and obtaining the maximum properties of the material being used in the product being molded.

The reciprocating screw is just another technique in the long series of technological efforts to permit better parts to be molded easier. I look upon the reciprocating screw in the same analysis as I studied the preplasticizing machine, the various heating cylinder designs and the rotating spreader. It is a tool or technique which can be used to obtain quality parts, but just the use of a reciprocating machine will not automatically produce these.

In our plant we have some parts which are produced in better quality and easier in plunger machines. In fact, we have a couple parts which simply will not run in our reciprocating screws. In discussing this with a principal of one of the better known machinery manufacturers, he posed the thesis that if we really worked on all the technology involved that we could end up by producing good parts on a reciprocating screw. To this, I'll agree. But, this just adds emphasis to my thesis that screws do not automatically produce quality parts.

One of the severe problems in molding, especially in a custom job shop, is the quality problem associated with contamination - either due to mixed colors or mixed materials. The screws are supposed to change colors and materials readily

and definitely. Those of you who have ever followed ABS with a clear material know that contamination problems can be severe. However, it must be stated that at least the screw can be pulled and cleaned, which is more than can be stated for the plunger machines. In our plant we make a standard practice of pulling screws when certain material changes are made to insure freedom from contamination. In this respect screws definitely make it possible to secure better quality, but this quality doesn't come as easily as it is advertised.

To illustrate this point specifically, I'll make reference to a new 1000 ton machine installed in our plant this past year. This machine will do a beautiful job of throwing pretty black parts out of clear polystyrene. We have come up with no satisfactory explanation other than we believe this to be material burning due to trapped gases. Screws are not supposed to act this way, but this one does. I personally believe the difficulty lies in the tolerances which exist between the flights and the barrel. We will correct this, but it is an example that screws can give some undesirable quality.

The uniformity of finish on a molded part can be achieved easier with a reciprocating screw. However, blush, gloss variation, weld lines and heat sinks can be just as severe on reciprocating screws as on conventional plunger machines. It is easier, however, to design improvement in these around screws than on plunger machines. So a definite advantage can be listed in this respect.

Maximum properties can be achieved only through the use of proper designed screws, shut-off valves, and drive speeds. Even in any given type of material it is sometimes necessary to alter these to achieve properties. All of this can be done, but it takes know-now and money. To achieve maximum properties the L/D ratio must be right, the compression ratio right, the dimensions and tolerances on the shut-off valves and tips must be right, and in most instances, what is right is not known. How many plants do you know with a range of screw designs for their machines? Here again quality is possible but few plants are achieving it. From intensive study in our own plant, I'll make the point that industry-wide the achievement of maximum material properties is not much greater off the screws than the conventional machines.

Warp of parts, in general, is considerably improved by screw molding. However, we have found certain grilles which turn out to be worse. Some grilles are best controlled by plunger speed and pressure variation at different points in the plunger stroke. This type control is difficult to achieve in the reciprocating screw. This is one type part which we get better parts off conventional equipment.

There has been much talk about excellence of shot control or weight control. It has been interesting to listen to the various machinery manufacturers' claims as to the weight control permitted by their particular valve design and their inferences that no other machinery manufacturer does quite so well. Here again, I'll say that industry-wide part weight variance, where this is critical, is no better off conventional equipment unless the molder tries to make it so. I have been told of slip ring movements as little as .040 to achieve control. I have also been told that the fit clearances have been made so tight as to freeze at less than operating temperatures to be able to achieve shot control.

In our plant, we use part weight as a quality control on many of our parts. On some parts this will be an hourly check, on others it will be a range check several times a shift. Non-flashing of parts is no indication of weight control. We obtain the best weight control off preplasticizing equipment using a positive stop - then this can only be true if the shooting ram leakage is consistent and there is no leakage around the rotary valve. Reciprocating screws can be made to

give weight control, but I venture a guess that there are more in operation not giving good weight control than those that are.

If reference is made to rigid vinyl, then a definite advantage must be cited for reciprocating screws. Molding of this material was virtually impossible off plunger machines. If any of you have ever tried to mold rigid vinyl off screw machines, I'm sure you will attest to the thesis that quality is not automatic. This material requires much specialization to achieve quality results.

In conclusion, it must be stated that quality off reciprocating screws will be a direct function of the molders dedication to quality and ability to accomplish this. If a molder is depending upon guidance by the machinery people or the material people it is not likely that he is producing any better quality from screws than off conventional plunger equipment. In summary, reciprocating screws make it possible to achieve higher quality - the technique is within our scope of operation - but, the machine you have or may buy may not produce the quality you expect without considerable analysis and revision.

8442-4

TOOL AND MACHINE REQUIREMENTS FOR PRECISION MOLDING

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INTRODUCTION

Injection molding at the Camera Works of the Eastman Kodak Company began in 1948 as a laboratory operation of insert molding plastics around glass lenses. The Korean War and the shortage of vital materials soon amplified the use of plastics in our products and by 1956 we were making an expanding line of acrylic photographic lenses and an assortment of component camera and projector parts. The significant step in our development came when, due to rising costs, we made the decision to run the molding machines in batteries with one man running more than one machine. Currently our operation of 56 presses, varying in size from 1 oz. to 56 oz. is divided into two distinct areas both of which are operated primarily for the manufacture of our own products. One area is a precision photographic lens section in which we manufacture our acrylic taking and viewing lenses, while the other section of the department is devoted entirely to component parts manufacture. The latter section is now run in batteries, with the exception of two presses. One man may be running as many as eight presses. It is to this latter portion of our operation, that this paper will refer.

PRECISION MECHANIZED MOLDING AND PRODUCT DESIGN

The concept of mechanizing a highly complex industrial precision part must start very early in the product design stages. It is the part design that sets the stage for all of the tooling and equipment requirements that will be needed when the part is finally manufactured. Although we have all heard this repeated over and over it is a lesson which seems difficult to learn. It usually is only when we find that we are unable to hold a tolerance or unable to insure with 100% certainty that a part is running automatically and we end up saying "if we had cored here or parted there", that we realize that what the designer did six months ago is making rejects for us now. Thus, the part design for automatic precision molding must be a "team" effort between the product designer, the manufacturing engineer, the tool engineer and the production department. Since the primary purpose of this paper is to discuss molds and equipment I will not detail all of the design considerations. However, let us remember that parting line problems, dimensional problems, possible irregular shrinkages, filling problems, finish and engineered material selection must be recognized before the toolmaker begins cutting steel. If this plan is not followed then the only result will be a rejectable product.

MOLD DESIGN AND CONSTRUCTION

The proper part design considerations are only the first step in the plan which will ultimately yield a part that will perform reliably in a product. The mold then becomes the center of attention, and experience with precision molds has proven that, regardless of how much care has been taken in design, or how uniform the material or sophisticated the machine, success or failure is finally dependent upon how well the mold designer has performed his task. Many mold designers consider their responsibility to be one of converting part print dimensions into a mold layout with the proper shrinkage calculations and a mold frame that will fit the molding rooms selection of presses. These are but a few of the minor details that will result in a precision molded piece. Let us consider then the elements that are required for a completely engineered automatic precision mold design in a sequence of logical order and importance. Although there are many details, some of which will be discussed shortly, there are four principal areas of concern: the first I shall call "anticipating functional part problems", the second "100% automatic molds", the third "temperature control", and lastly but certainly far from the least important "mold maintenance".

A mold designer's first consideration in preparing to create his design is a completely thorough understanding of the function of the part in the product and all of the limitations and tolerance considerations that will be required. He must analyze for example the effect of flash on the product. Here we are not talking about the gross P.L. flash and ejector flash that we know from the beginning is unacceptable, but rather the .005" of flash which will occur eventually. There are many examples in our shop where the product can allow flash in a particular area and perhaps in a particular direction but not in others. An example of this on a simple part like a gear may well determine the designer's choice of possible parting lines and ejector placement or even the type of ejection system to be used. The problem is compounded as the complexity of the part increases and in most cases this requires even more engineering consideration of the problem.

Abnormal shrinkage or non-uniform shrinkage has always been a concern for the mold designer but it is more of a problem on the precision part. Naturally it is not always possible to predetermine what will be the exact amount of this shrinkage, but certainly a thorough understanding of the material characteristics and the part geometry will be a major guide. We all know that changing section thickness, direction of flow, and mold temperature are among the parameters that have a direct bearing on the resulting tolerance. Recognizing the possibilities should immediately indicate to the mold designer that he may well have to section the mold to allow for future adjustment. Recognizing the possibilities may well determine the direction of a tolerance that he may choose. If the section is to be a female member, for example, he may choose to stay on the low side of a tolerance so that stock may be removed in the future if need be, rather than weld the section if the part tends to go on the high side of the tolerances in relation to shrinkage.

Ejection system for molds is another area in which particular care and attention are required. The normal approach of designing the mold with all of its section and cores, and then placing ejectors wherever they can be placed has created many distorted and stressed parts. It is becoming more evident with the more exotic low shrink materials that ejection cannot be an after thought but must be well thought out and planned. There are examples of parts, that require tight flatness and size tolerances, where it has been necessary to redesign the ejection system after the initial run, due to a twisting action during ejection. This, of course, causes unnecessary extra cost and delay which no one wants. It is now common practice to design the ejector system as an integral forming section of a mold to accomplish multiple purposes such as undercutting sections that, when the

ejector moves forward, will cam inward to release the part. When we consider the many responsibilities of an engineered ejector system on the function of a part, it is realized that the total ejector system must be anticipated long before the design is on a sheet of drawing paper.

The final comment in this section of the paper will be a warning to emphasize the point that the mold designer is in the best position to see the entire concept and function of each part and, by his careful engineering analysis and design, a much more accurate part may result. On many parts the problems may be so complex that the only solution for the mold designer may be to build a prototype mold to answer some of the basic questions. We have found it necessary in all cases for the mold designer to detail completely every member of the mold with each and every dimension so we can be assured nothing is left to chance for the toolmaker.

100% AUTOMATIC MOLDS

Battery operation of injection molded parts is not as difficult as most molders seem to think. For the most part there are two basic considerations - (1) on each and every shot the parts and runner must be ejected free of the mold and (2) the runner must be separated from the part. The first of these, generally presents the largest problem for the mold designer. The ejector pin placement that the mold designer chooses is of first importance and, assuming the decision has been made in the best interest for the function of the part, the designer may well find himself with an ejection system that traps the part so that it is not free to fall with gravity. The mold designer who depends only on gravity can expect to see damaged molds. What, then, are some of the dependable systems that are available?

Among the simpler systems is a "kicker pin" (Figure 1). By placing a rocker under the ejector head and hitting a stop the kicker pin will advance one pin ahead of the other ejection pins, thus unbalancing the part and allowing the part to fall free of the mold. Another dependable design, but far more costly, is a double ejector system (Figure 2). In this system two ejector assemblies are employed. One acts as the primary cavity ejector and the second, usually separately powered with air or hydraulic cylinders, acts as the stripping ejector and frees the part from the primary pins. This technique is usually employed in deeply cored parts or when the primary ejectors are performing a core function and may be buried in the part.

Hydraulic and air ejection systems, which are independent of the press mechanical knockout system, are growing in popularity. The advantage of each of these systems is their ability to retract before the mold closes and to stage this system into the mechanical knock-out system of the press. These ejectors are usually very rapid in their movement forward and provide momentum to literally throw the parts off the ejector pins.

The use of die wipers is a good guarantee of part removal where cost prohibits extensive tooling. The inaccuracy of the die wiper and damage to the mold or parts has been eliminated for the most part with more adequately designed wiping systems and press interlocks (Figure 3). A design which we have found to be very satisfactory utilizes an air cylinder with a good lower bearing and a secondary guide rod and bearing which gives accurate up and down motion to the wiper. The cross bar connecting the shaft of the cylinder and guide rod is drilled and tapped to accept whatever actual wiping device is required for the particular job being run. In our case this may vary from a fine bristle nylon strip brush on very delicate jobs, to a piece of sheet nylon or polypropylene on less critical jobs. In some cases a wedge shaped blade is used to act as a cam to remove the parts trapped

on the ejector pins. However, several very important controls must be placed on any die wiper to make it operate satisfactorily. They include a limit switch wired into the closing circuit of the press which will not allow the press to close until the wiper has returned to its up position and a recycle delay timer in the mold open circuit to insure sufficient time for the wiper to actuate and the parts to fall free. Speed control of both the downward and upward motions of the wiper are vital since this will in many cases determine the wiping action and eliminate possible damage to parts. The last device which we use is an air safety unit which prohibits the wiper from working in the event of an air failure or the accidental disconnection of the air while the machine is cycling. This is a spring loaded 1" diameter air cylinder which, if the air fails, moves forward and prevents the main cylinder from coasting downward.

The wiper then provides a mold designer with considerable flexibility in his approach to the specific problem before him. With the use of a wiper we have found it possible to mechanize even low production jobs without any increase in basic mold cost and, by employing two wipers on the same machine, we can insure runner removal on three plate molds.

The second portion of the battery operation problem, that of detaching the part from the runner, is perhaps a little more routine. Tunnel gating and three plate molding accomplish this task by the very nature of their design. The three plate design however does require some consideration of runner removal. Means must be taken to insure that the runner stays on either the center plate or on the nozzle side of the mold so that it can be wiped free of the mold. There are two systems of snapping the runner free in three plate molds that we are currently using which may be of interest. One uses a stripper plate next to the upper clamping plate (Figure 4) with sucker pins in the runner retained in the clamping plate which holds the runner in the desired position (on the nozzle side of mold). When the stripper plate moves forward a distance determined by stripper bolts, an air hole is exposed around the sprue bushing and the runner is blown away.

The second system used in three plate molding, also employs a stripper plate but retains the runner on the center cavity plate and relys on the snap action to clear the runner (Figure 5). In this design, one set of stripper bolts connect both cavity plates and a second set connects the stripper plate and the clamping plate. Sucker pins again hold the runner in position and, when the mold is fully open, snap free and throw the runner free of the mold.

Edge gating requires a somewhat more complex design especially where no tab is allowed. One of the designs which usually results in an even and clean scar utilizes a basic punch and die principle (Figure 6). In this case, sections of both the upper and lower half of the mold are stiffly spring loaded. One moves with respect to the other, thus shearing the gate as the mold opens.

A significant consideration for the designer in battery operation of a precision mold is what happens to the part once it is out of the cavity. The manner in which a part falls out of the mold and on to a conveyor or slide in the bed of the press may determine the damage to the part. Baffles to break the fall may be required and attention to elements connected to the bottom or sides of the mold is required. Parts in the future require the use of some rather complex devices to remove the parts individually from each cavity and perhaps release the parts on a surface outside the press.

In summary, the mold designers approach to battery operation of a part is basically a problem of attention to detail. He must consider and solve all of the

details surrounding the part, the mold and the molding machine which include detaching the part from the runner, insuring perfection in runner and part removal from the mold without damage in order to be certain of an automatic mold. The only economical place to do this engineering is on the drawing board.

MOLD TEMPERATURE CONTROL

The importance of mold temperature control and the mold designer's engineering considerations has been the subject of perhaps more papers presented to molders than any other single subject and yet we, as molders, apply less science to this phase of our job than perhaps to any other. My object in this discussion will not be to present data on heat transfer rates or even rules of thumb for water channel placement, but I will outline a few techniques for doing a more uniform temperature control job. All of these techniques involve getting the cooland into the cavity block or immediately around it, thus eliminating one insulating barrier loss between the plate and the cavity block. The first technique involves coring the cavity block itself and piping through the cavity plate directly into the cavity. This is certainly the least complex of the various systems to be presented but it must be remembered that, when the pipes are removed for any reason, the leak between the cavity and plate is a source of rust and the cavity surfaces must be protected. The next two techniques (Figure 7) to be mentioned involve the use of "O" rings which we have found to be satisfactory after we learned that it is necessary to clamp the two members together. In the first design, water channels are bored through the retainer plate and others at 90^{o} to match holes in the cavity block, "O" rings are placed between the joints and the members screwed together. This technique is particularly useful when used in conjunction with other systems as a means of getting water to particular cores. Another "O" ring technique requires grinding grooves around the cavity and placing "O" rings at two levels and again channeling into the cavity plates. This system is effective only with relatively small round blocks but has proven to be quite efficient.

These techniques are examples of the mold designer providing multiple zones of heat within the mold itself which, in many cases, is a significant problem for the molder. We have mentioned previously the sometimes staggering problems of differential shrinkages due to changing section thickness, and the complex material flow patterns in the cavity which can be controlled far more successfully if the molder has the ability to control the temperature at critical points within the mold.

The control of mold temperature even at its best is still rather crude. Molders should be pushing mold builders and equipment suppliers continuously for better answers to this problem. Certainly a mold material that will more efficiently dissipate heat than steel and yet withstand the high molding pressures and wear of the precision molding operation is badly needed. Some of the newer aluminum and beryllium alloys have been used in limited applications but both have some major drawbacks for extensive cavity use. Perhaps eventually we will see some materials from the U. S. Government Space Program that will be applicable to injection molding.

Equipment for mold cooling has been developed rapidly over the past few years but we have yet to see a practical system for alternately heating and cooling molds. Such a system would present vast new horizons for the molder. A few companies are in the experimental stages of this development which we will be looking forward to, although the efficiency of any dual system may be dependent upon the new mold materials mentioned previously.

DESIGNING FOR MOLD MAINTENANCE

The last portion of the mold designer's task to be discussed in this paper is that of designing for minimal and future maintenance. We will devote no time to the various basic mold types other than to mention the molders' usual preference for two plate molds due to their simplicity and history of lower mold costs than other designs. Before progressing, however, let us remind the mold designer of two basic considerations. First, that the simplest design to do the job will always cost less to maintain; and second that providing enough supporting steel should be a first time cost only since the constant readjusting of a mold due to a lack of steel ("beef") creates continuing tool costs and costly losses in production.

There are two areas of concern, however, where the mold designer can very definitely reduce mold maintenance. The first is in the selection of mold materials. While each mold designer and toolmaker have their own preference for materials, the steels must meet four tests. The first is availability, which is becoming a surprising problem. Steels that may be available in one area of the country may not be readily available in other sections of the country. If substitutions are necessary, the molder must be aware of it so proper precautions in welding or re-heat treating may be taken. Secondly, the steel must be able to be welded for future changes and repairs. Advances in welding techniques have made this process a very useful tool to all molders and mold builders. However, if the basic material cracks or distorts, it is of no use. Third, it must be a stable steel that will harden uniformly and adequately and dimensionally stay within known parameters. Lastly, the designer must consider the physical characteristics of the steel. Brinelling, shock resistance, and thermal shock properties are important. The ability of a molder to repair the mold in the press is again dependent upon the mold design. The feature of being able to remove a section or even an entire cavity while allowing the remaining cavities to continue in production will greatly reduce costs. Currently this is rarely considered by mold designers. In those instances where we have designed the mold with future maintenance in mind, our production record and maintenance costs are greatly improved.

Perhaps a final comment on maintenance relative to the number of cavities is in order at this point. Many molders look at only the unit cost of a part as being the one significant factor but this may be only a partial consideration. It would seem that the total product cost; that is the total labor, total tool cost, accurate tool and machine maintenance costs, and machine running costs may be a better determination. This approach usually leads the molder toward fewer cavities particularly if the product is battery operated and labor is a small factor.

In any discussion of mold design and molds for precision automatic molding the actual building of the mold must be ignored and therefore let us examine briefly two aspects of the mold construction - craftsmanship and the use of electrical discharge machining equipment.

The craftsmanship involved in building a precision mold is becoming a serious problem for many molders, ourselves included. If the mold designer has completely detailed his drawings and gone through the various considerations mentioned previously for a particular mold, then the mold builder must accurately machine all of the components within the limits on the drawing. This accuracy only will provide the molder with a tool that will perform satisfactorily. The toolmaker must establish all of the fits in a mold with a knowledge of the requirements and the material to be used. Each member of the mold must be assembled and aligned with a knowledge of the part requirement and as near the mold design nominal tolerance as possible. Mold finish is an area of growing concern. In precision molds, a finish that looks good may be far from satisfactory. Again the cavity finish require-

ments are related to what is expected of the part. With the complex geometry of some parts and with tolerances in the range of what is now expected in metal cutting when very low shrink materials including the assortment of filled materials are used even microscopic imperfections will cause a part to distort when ejected. New polishing techniques and more homogeneous materials are definitely required but, even with these, a great deal of skill will be required of the toolmaker.

Although no attempt will be made here to discuss all of the modern machine tools, electrical discharge machining has been outstanding in its adaption to precision mold manufacture. The use of EDM equipment has opened a whole new horizon to precision mold makers and many of the current mold design are dependent upon the use of this equipment. Geometrically complex configurations that previously were difficult if not impossible are now available. The use of EDM for making such things as helical gears, and three dimensional surfaces is now commonplace in many shops and recent trends toward extreme detail with use of EDM have made this tool one that is becoming "life blood" to many shops. When older methods were used to accomplish some of these complex shapes, a great deal of sectioning was required which in many cases greatly increased the size of the cavity block and perhaps even created the need for larger mold bases. Modern EDM equipment has allowed a general reduction in tolerances due to the facility of stock removal after hardening, since expansion or contraction as a result of hardening is no longer a factor. In addition to all of the technical advantages to this process there seems to be a very definite cost advantage. Although this will depend greatly upon the particular operation to be performed, the average cost advantage in our plant is figured to be approximately 25%.

It is obvious then that accurate machine tools and up-to-date techniques are vital to success in the fabrication of precision molds but, by the same token, neither of these will ever replace skilled workmanship which, in the final analysis, is the prime requirement of mold construction.

MOLD MACHINE

In the final portion of this paper I would like to discuss the molding machine. I will not discuss the screw machine since much of the debate on advantages and disadvantages has been settled. It must be realized again, however, that any molding machine is a series of compromises for the molder and he makes it even more of a compromise by the fact that he expects it to produce equally well with a variety of jobs and shot sizes. There are certain aspects of the machine design however which, if given more engineering consideration, could make this compromise a little less of a problem for the precision molder. High injection pressures that can be controlled very accurately and staged at different levels during the injection period are desirable on precision parts, for the most part, allow very small gates. Currently, precision gears and cams are being run on machines in our plant with pressures as high as 23,000 psi which is not available on most standard machines. Pressures may be indicated with a standard pressure gage calibrated in 100 psi increments which hardly seems adequate. The point of pressure measurement which to date has been on the inlet side of the injection ram may well be an area for future review. Perhaps transducer measurement of pressures at the nozzle may be a more accurate approach to the problem with a feed back system for correction similar in principle to the temperature control systems currently being used. A transducer pressure recording device is currently being used experimentally in our plant and has proven to us that present pumping systems seem quite capable of uniform supply. However, the pressure control and adjustment systems currently used provide for only a very gross change.

Related, of course, to pressure at the nozzle is the control of melt temperature. The screw machine without question has provided a great deal of temperature control to the molder but refinements are still required. In many areas variable voltage is a considerable problem and as progress is made in precision molding, it is probable that voltage regulation on each machine will be required.

The addition of Variacs to the commonly used proportional temperature controllers provides additional control by allowing the voltage applied to the heat zone to be reduced to only what is required. This system has proven to be a useful method of reducing temperature variations. Temperature controllers of the time frequency type are available which perform in much the same manner as the Variac system just mentioned and are reported to be sensitive to $\pm\frac{1}{4}^{\circ}F$. Development of oil heated cylinders is underway in some companies and it is reported that tests to date have eliminated temperature variations for all practical purposes.

In addition to refinement in the molding parameter controls refinements in certain of the mechanical aspects of the equipment seem in order for precision molders. Maintaining platen alignment for precision molds is a significant problem on some molding machines. The usual construction of molding machines makes maintenance of the "ways" very difficult and adjustment impossible in many cases. Tie bar loadings are factory adjusted but no indicator is provided for a change which certainly occurs during operation. In the future considerably more engineering thought must be given to this mechanical maintenance feature if ultra-precision on molded parts is to become a reality. Precision molds are generally very delicate and there has been no substantial change in low pressure closing systems in recent years. Certainly photoelectric protection systems may present an answer for the equipment designer. Precision molders usually require larger platens for any given shot size due to the complexity of their molds. Today larger platens usually mean larger shot capacities. Perhaps modular designed machines, which give the molder a selection of clamp ends and injection ends, would provide the molder with more flexibility and control over the molding machine performance.

CONCLUSION

Thus we may conclude that precision molding is a problem of control. The control for the different groups involved may mean slightly different things, to the part designer an awareness of the limitations of the process and his part, to the mold designer an awareness of the total concept of the part function and the corresponding controls he must place in his design, to the mold builder the ability to produce a mold accurately to the design. Finally, the molder must have the sophistication of fine machine controls to produce an acceptable part.

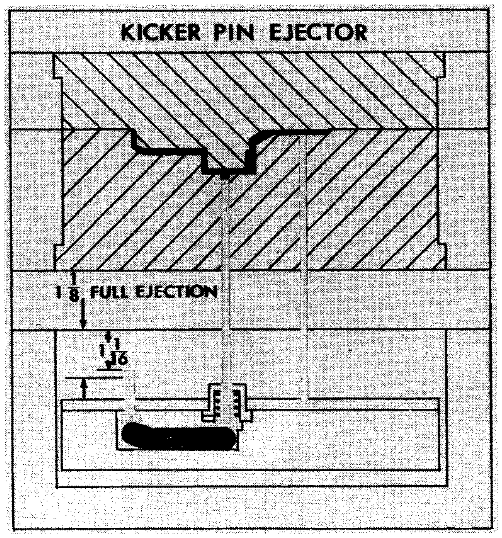

FIGURE 1

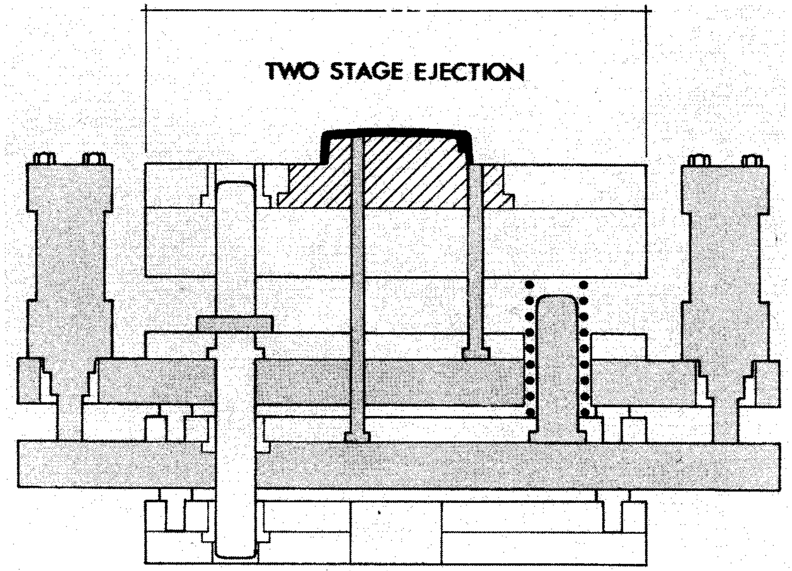

FIGURE 2

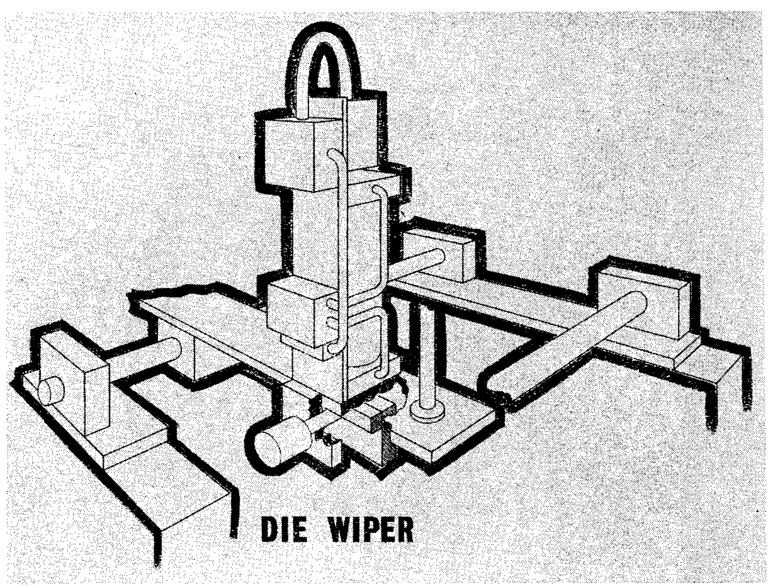

FIGURE 3

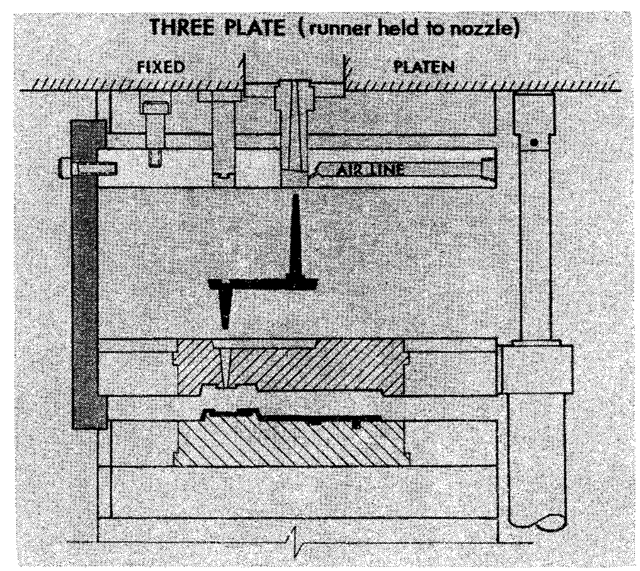

FIGURE 4

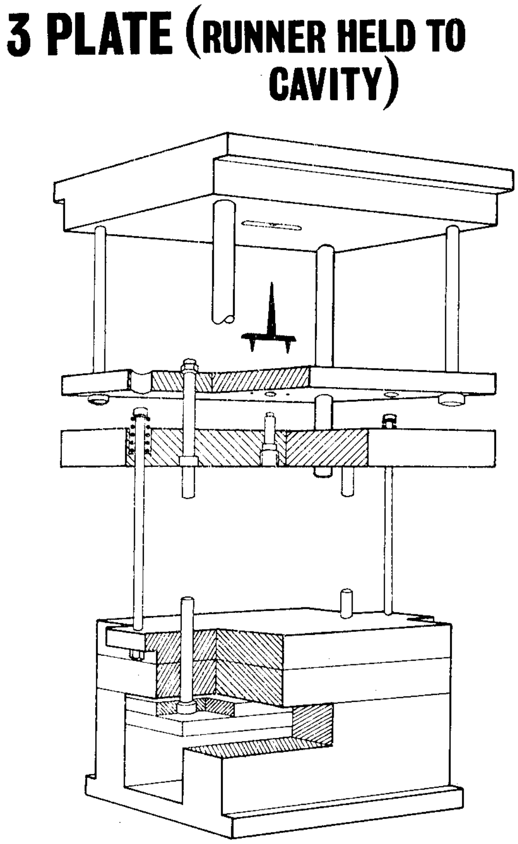

FIGURE 5

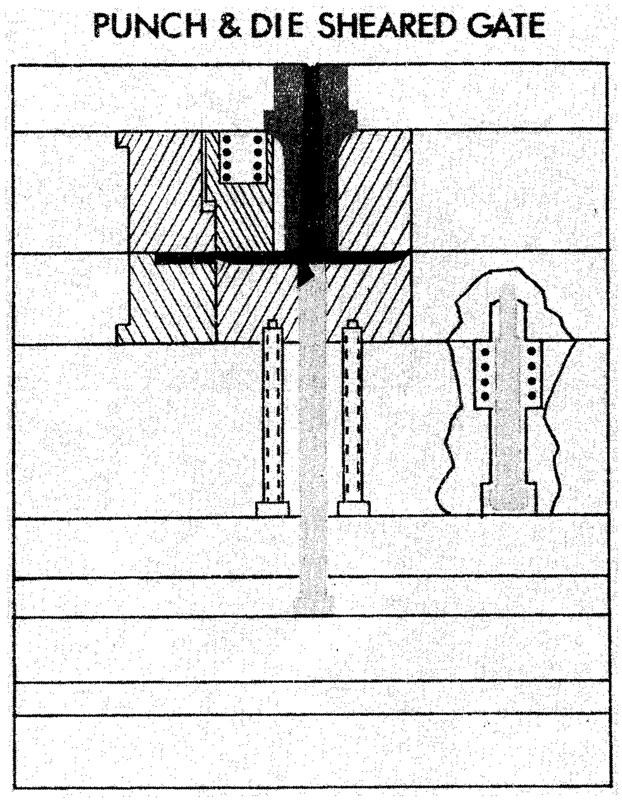

FIGURE 6

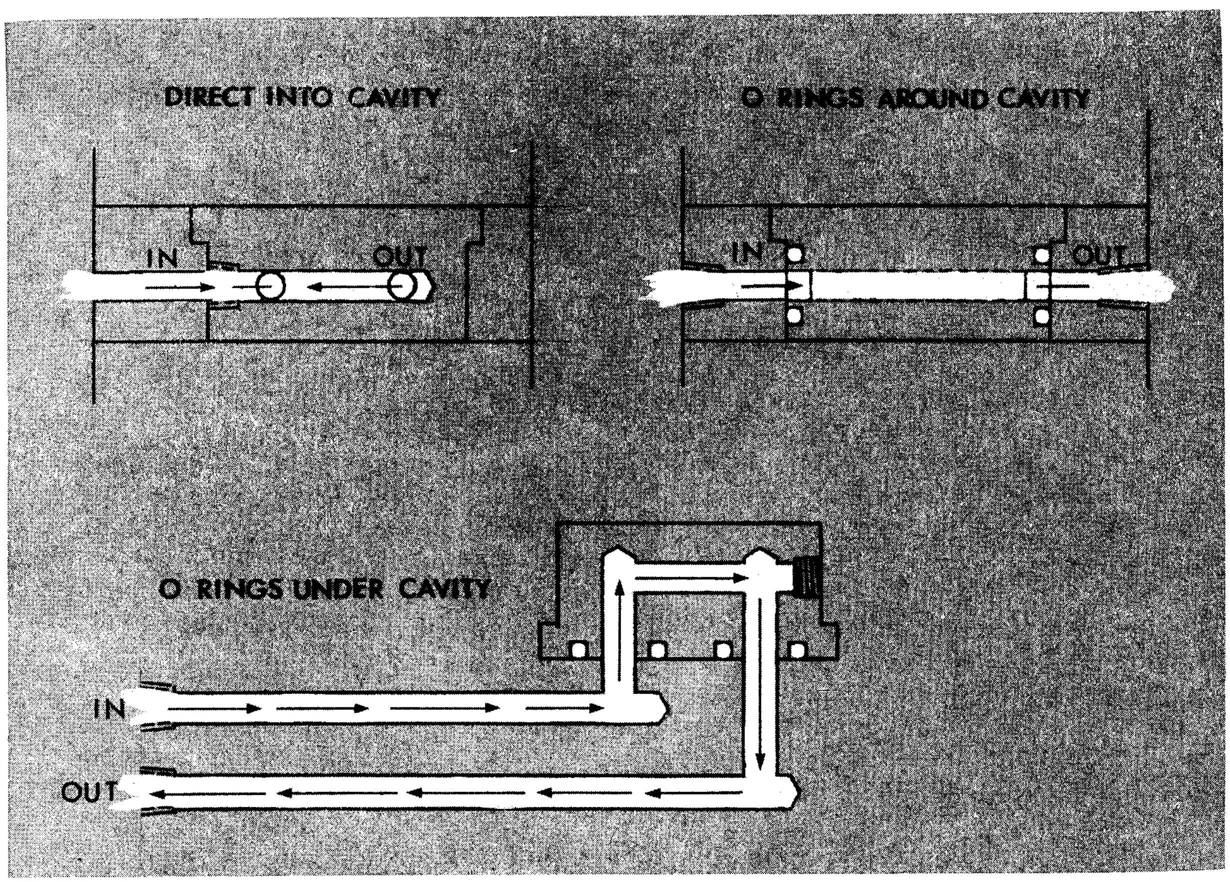

FIGURE 7

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MATERIAL PARAMETERS FOR INJECTION MOLDING

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INTRODUCTION

Automation of the injection molding process is the goal of every molder who runs high production items in his shop. A great amount of work has been done in the area of mold design, auxiliary equipment, and the injection molding machine itself to accomplish this goal but one critical question remains to be answered: Are the polymers marketed today ready for automation?

We would like to give you a little insight into those parameters which we feel are the important ones to be considered in answering this question.

FLOW PROPERTIES

Using an Instron Capillary Rheometer, we have studied the flow properties of a wide range of commercial thermoplastics. Our laboratory has also been involved with injection molding these same materials into finished products. From this type of work, it was found that the flow characteristics of a polymer in the injection molding machine, through the runner system of the mold, and into the part cavity can be correlated to the flow in an Instron Capillary Rheometer. This instrument was developed by Merz and Colwell as a research tool at Monsanto Chemical Co.

As shown in Figure 1, the rheometer provides for extrusion of a carefully temperature controlled polymer melt through a capillary. By incorporating the rheometer in an Instron Universal Testing Machine the polymer can be extruded over a wide range of rates. A continuous trace of load versus time is made through the load cell to the Instron chart recorder. The wide range of rates and temperatures over which this equipment can be operated permits us to completely describe the processing characteristics of a polymer in a usable and practical form. Other commercially available devices for viscosity measurements, such as rotational viscometers and melt indexers, are much more limited in their ability to adequately describe flow behavior, particularly with respect to the high shear rates which are encountered in injection molding.

The change in viscosity of a polymer with shear over a wide range of rates is an important parameter. It is a measure of the processing flexibility which is inherent in the polymer. Viscosity data for three different materials are plotted in Figure 2. The materials are a polycarbonate, a high impact polystyrene and an ABS. The apparent viscosity of each is shown as a function of temperature at two shear rates. The first rate, 10 sec.$^{-1}$ is typical of shear rates encountered in

the extrusion process while the second, 1000 sec.$^{-1}$, is more typical of the high shear rates obtained in an injection molding process. As you can see, polycarbonate is not too dissimilar from a typical ABS at the lower shear rate which indicates that both could be extruded at similar conditions. This is found in practice and the temperature of extrusion for both is in the neighborhood of 500°F. However, to injection mold a material requires much better flow, lower viscosity, than does extrusion. The ABS responds to the shear of the injection molding process, and its viscosity is substantially reduced. The polycarbonate, on the other hand, is not nearly as shear sensitive and its viscosity is only slightly reduced by this large increase in shear. This means that temperature is the only parameter that is effective in reducing polycarbonate viscosity to a level that is suitable for injection molding. Therefore, the temperature for molding is 50-150°F. higher than that for the extrusion of this polymer. In the case of the ABS and HIPS, on the other hand, shear is a very effective means of reducing viscosity and the temperatures for extrusion and injection molding are not substantially different.

A ratio of the viscosity at a low shear rate to that at a high rate can be used as an index of shear sensitivity. Using the viscosity at 10 sec.$^{-1}$ and at 1000 sec.$^{-1}$ for this purpose polycarbonate has a 10/1000 1.5; ABS has a ratio of 30; and HIPS has a 10/1000 20.

This does not mean that a high shear ratio is always desirable. Rigid PVC, as an example, is only thermally stable over a narrow melt temperature range. A high 10/1000 ratio though desirable from the standpoint of reducing viscosity with shear can present other problems with this material. Because of its high viscosity at any temperature below the degradation temperature it is a difficult material to mold in complex parts. As a melt temperature of 400° is approached to reduce viscosity, the shear sensitivity of the polymer becomes a very critical factor. A slight increase in shear through increased ram speed, screw speed, or back pressure will reduce the viscosity enough to fill the part but a percentage of the energy absorbed from shear can result in a temperature rise and polymer degradation.

Materials of equal viscosity will require the same pressure to fill a given mold. A pressure at which the cavity "just fills", we refer to as the short shot pressure. The best correlation of viscosity to this short shot pressure with a number of polymers is found to occur at a given shear rate. For viscosities measured above or below this shear rate the correlation is poorer. If a shear rate is found at which a correlation exists for a great number of materials, this shear rate can be assumed to be the dominant of "controlling" shear rate. The results of a study made in the laboratory with a number of HIPS and ABS materials is shown in Figure 3. A good correlation of viscosity to short shot pressure was found at 3500 sec.$^{-1}$.

It should be emphasized that this "controlling" shear rate is only applicable to this equipment and this mold but the order of magnitude is very significant. Much viscosity work in the past was done at much lower shear rates and poor correlation of viscosity data to injection molding behavior was obtained. This tool was therefore not effectively used to screen and control polymers.

On a number of occasions we have actually found better moldability with polymers where reported vendor data for flow properties (melt flow rate and other low shear methods) would indicate that they were more difficult to process. In these cases the polymers were more shear sensitive than supposedly better processing materials of lower viscosity at low shear rates. Therefore, at high shear rates related to injection molding the viscosity relationships were reversed and ease of injection molding correlated with these latter values.

RELATIONSHIPS TO PHYSICAL PROPERTIES

Material suppliers have normally used physical property data as their measure of the control of quality of given batches of material. Very little use has been made of close control limits on viscosity, which is just as important. Unless compensation is made in molding conditions for resin viscosity variation, one of two things will result. If the variation is large enough, the part will either not fill or flash. This is fortunate because it is a visible indication of trouble and necessitates changes in molding conditions. The other possibility, where no visible indication of trouble occurs, is a much more dangerous situation. In this case mechanical properties of the moldings are affected. Here quality can suffer, unknown to the molder.

In Figure 4, the batch to batch variation is viscosity of one company's standard HIPS material is shown. In order to obtain the same viscosity for the most viscous batch that would be obtained with the least viscous batch at 400°, its melt temperature would have to be approximately 435°. This means that when these materials were molded, changes in melt temperature of as much as 35° had to be made to obtain the same viscosity and therefore the same quality in the finished part.

There is absolutely no doubt that batches which vary this much could not have been molded satisfactorily in a critical automatic mold without changes in conditions as new batches were molded.

But what of quality variation due to these viscosity changes?

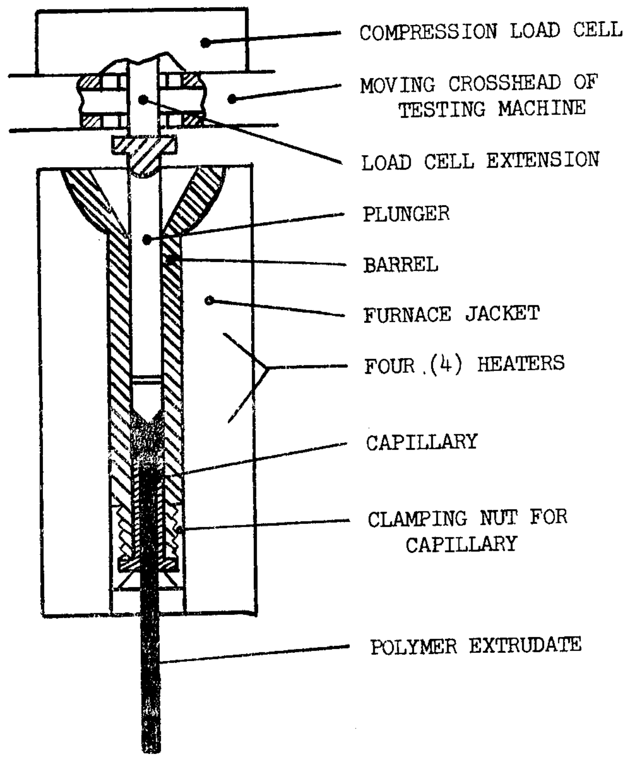
In Figure 5 is shown uniaxial impact (notched Izod) data along with falling weight (multiaxial) impact data for a medium impact ABS. If two batches, which varied as much in viscosity as the two which we have been discussing, were molded at the same temperature, a difference in impact of approximately 7 inch pounds could be expected. This is a percentage loss of between 20 and 70%, depending on the melt temperature selected.

Orientation plays a large role in this variation of impact with temperature as is illustrated by the uniaxial Izod impact data. At the lower melt temperatures the "in-flow" impact strength is approximately four times higher than the "across flow" strength showing a high degree of orientation. As the melt temperature is increased, the "in-flow strength" decreases while the "across flow strength" increases. At a temperature of approximately 525°F., degradation begins and impact strength falls off in both directions as does falling weight impact.

CONCLUSION

in injection molding
is illustrated

All of these data illustrate the need for a consistent polymer. If the evaluation of a molded item is made with a given batch of material of a given viscosity, subsequent batches of greatly varying viscosity will not give equivalent quality when molded under the same conditions. Viscosity, therefore, is a parameter which should not be overlooked in material specifications. In addition, the correlation of polymer viscosity with injection molding performance requires an understanding of the shear rates involved in this process. Viscosity measurements made to determine molding behavior must then be made at these shear rates.



INSTRON CAPILLARY RHEOMETER

FIGURE 1: Instron Capillary Rheometer

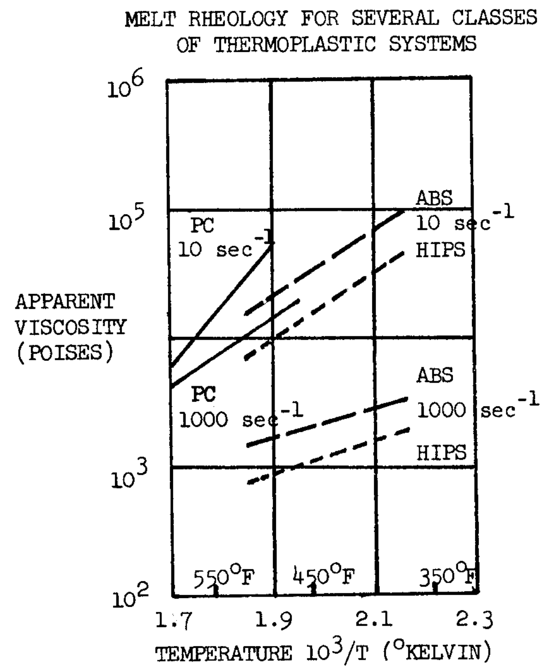


FIGURE 2

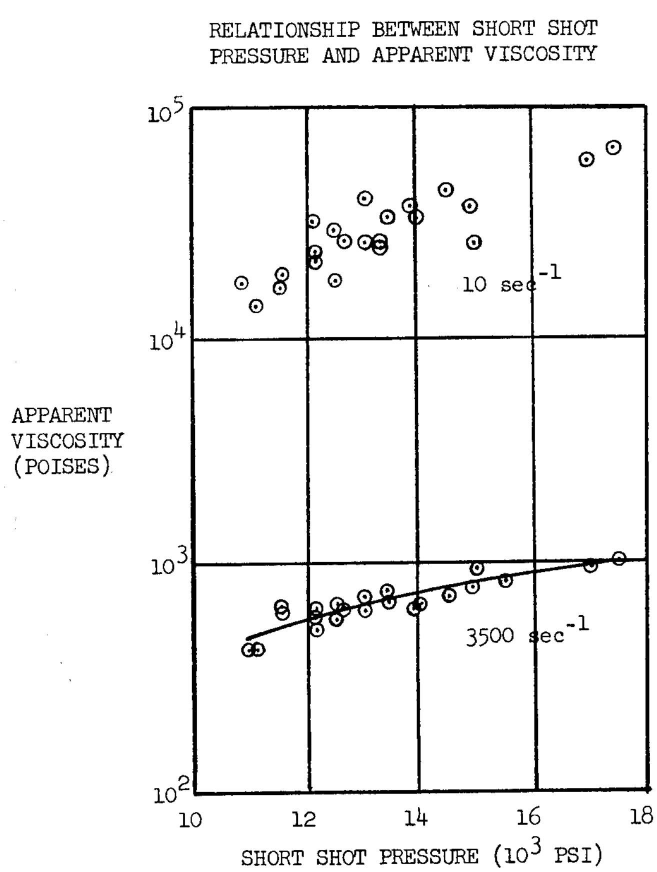


FIGURE 3

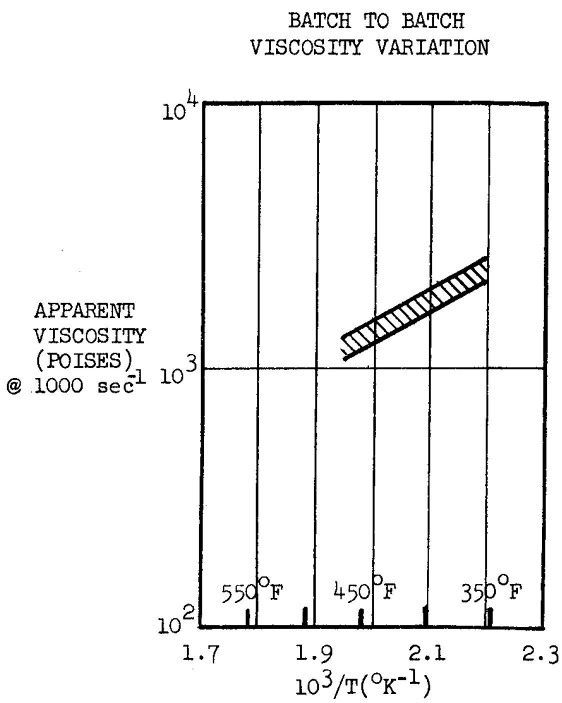


FIGURE 4

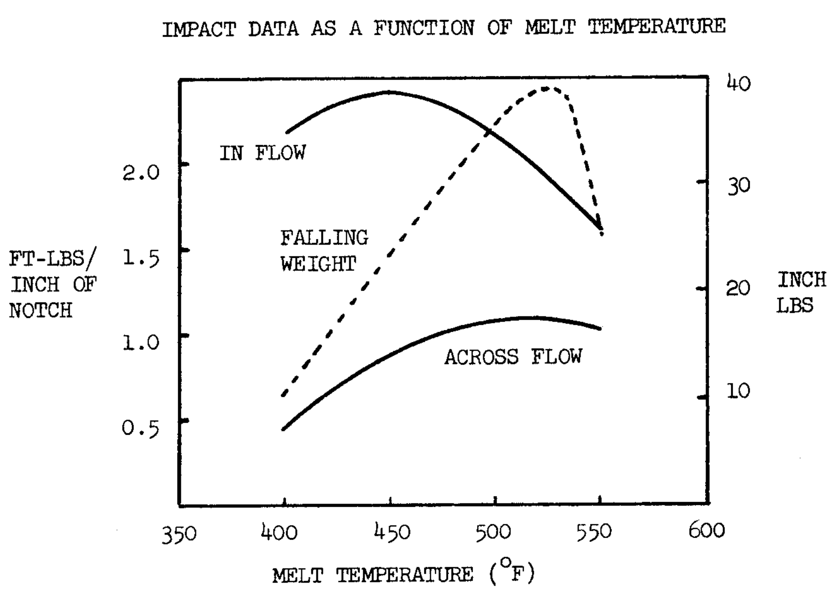


FIGURE 5

INITIATION FEE MUST BE ATTACHED FOR PROCESSING.

SOCIETY OF PLASTICS ENGINEERS, INC.

65 Prospect Street, Stamford, Conn. 06902

348-7528 AREA CODE 203

MEMBERSHIP APPLICATION

PLEASE PRINT OR TYPE

Executive Office Use Only

I.D. No. ______

Ack. ______

Elected ______

I hereby make application for { ☐ admission into ☐ reclassification within ☐ reinstatement in } the Society of Plastics Engineers, Inc. in the grade of membership indicated below for which I believe I am qualified. (See instructions on reverse side.)

Grade	Initiation Fees	Annual Dues	Foreign Dues
☐ Senior Member	$10.00	$20.00	$17.50
☐ Member	10.00	20.00	17.50
☐ Affiliate Member	10.00	20.00	17.50
☐ Student Member	None	5.00	5.00

I wish to affiliate with the ______ section.

(Geographical location. See listing on reverse side.)

Applicants Full Name ______ (First) (M.I.) (Last) (Citizen of) (Birthdate)

Please fill in both addresses and **CHECK THE ONE TO WHICH YOUR MAIL SHOULD BE ADDRESSED.**

☐ **BUSINESS:** Company Name and Division: ______

Position ______

Address ______ City ______ State ______ Zip Code ______

☐ **HOME:** Address ______ City ______ State ______ Zip Code ______

REFERENCES The By-Laws require the names of three references who are familiar with your work. One of them should be a member of the Society. Assistance in providing member-references, when needed, will be given on request.

1. ______ Address ______
2. ______ Address ______
3. ______ Address ______

STATEMENT OF COLLEGE WORK

Years Attended		Institution	Major and Minor	Degree	Experience Credits See reverse side
From	To				
				Total Education Experience Credits	

RECORD OF QUALIFYING EXPERIENCE IN PLASTICS

Dates				Give your title, name and location of employer, and name of immediate superior for each position. List in chronological order. Describe duties fully and state briefly any important engineering work you have done in in each position. If space is not sufficient, use a separate sheet.	Time in years and months
From		To			
Mo.	Yr.	Mo.	Yr.		

I certify that the statements made in this application are correct. I agree, if elected, to be governed by the Constitution and By-Laws of the Society, and to promote the objective of the Society.

Total qualifying years of experience.

Total education and qualifying experience credits.

CREDENTIALS COMMITTEE USE ONLY

Approved (Signature) Date

Approved (Signature) Date

Date of Application ______ Signature in ink. ______

COMPLETING THE APPLICATION

Grade of Membership . . .

Membership grades are based on experience credits which are earned as follows:

1. **Experience credits earned for education.**

   Doctorate in science or engineering subject: **6 credits**
   Masters in science or engineering subject: **5 credits**
   Bachelors in science or engineering subject: **4 credits**
   Other degree in non-science or non-engineering subject: **2 credits**

   Maximum credits allowable for education shall be six (6).

   When filling in the "Statement of College Work" on the reverse side of this application, please place the corresponding number of credits earned in the right-hand column.

2. **Experience credits** for qualifying experience in plastics or plastics engineering are earned at the rate of one (1) per year, e.g. 5½ years of qualifying experience = 5½ credits. *Please detail carefully the engineering skill required for* ***each position*** *to help the Credentials Committee judge experience as "qualifying."*

   When filling in the "Record of Qualifying Experience in Plastics" on the reverse side, please place the amount of time spent in each position (in years and months) in the right-hand column.

When you have determined the number of credits which you believe you have earned consult the following membership grade requirements. Indicate on the reverse side the grade of membership for which you believe you are qualified.

GRADE	REQUIREMENTS
Senior Member	Minimum of twelve (12) experience credits and maintained continuous membership in the Society for a minimum of two (2) years.
Member	Minimum of six (6) experience credits
Affiliate Member	Less than six (6) experience credits
Student Member	Regularly enrolled student (full- or part-time) in a course of study in plastics and between the ages of 16 years and 26 years, inclusive.

SPE SECTIONS

AKRON
ARIZONA
BALTIMORE-WASHINGTON
BARTLESVILLE-TULSA
BINGHAMTON
BUFFALO
CENTRAL INDIANA
CENTRAL NEW YORK
CENTRAL OHIO
CHICAGO
CLEVELAND
CONNECTICUT
DELAWARE VALLEY
DETROIT
EAST CENTRAL ILLINOIS
EASTERN NEW ENGLAND
FLORIDA
GOLDEN GATE
HUDSON-MOHAWK
JAPAN
KANSAS CITY
KENTUCKIANA
MIAMI VALLEY
MID-MICHIGAN
MILWAUKEE
MONTERREY
NEW YORK
NEWARK
NORTH TEXAS
NORTHERN INDIANA
NORTHWEST PENNSYLVANIA
OMAHA
ONTARIO
PACIFIC NORTHWEST
PALISADES
PHILADELPHIA
PIONEER VALLEY
PITTSBURGH
QUEBEC
ROCHESTER
ROCK VALLEY
ROCKY MOUNTAIN
ST. LOUIS
SOUTH TEXAS
SOUTHEASTERN OHIO
SOUTHERN
SOUTHERN CALIFORNIA
SOUTHERN NEW ENGLAND
SOUTHWEST VIRGINIA
TENNESSEE VALLEY
TOLEDO
TRI STATE
UPPER MIDWEST
VIRGINIA-CAROLINA
WESTERN MICHIGAN
WESTERN NEW ENGLAND
NON-SECTION

MEMBERSHIP APPLICATION

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